Hydraulic systems

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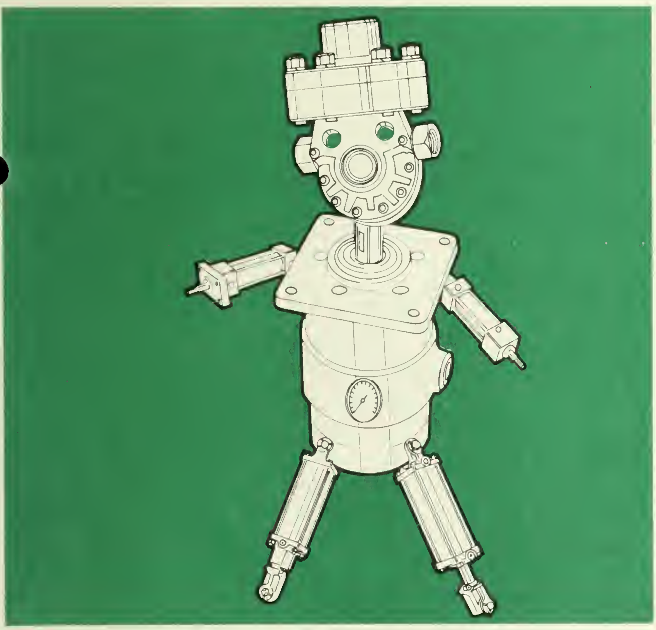

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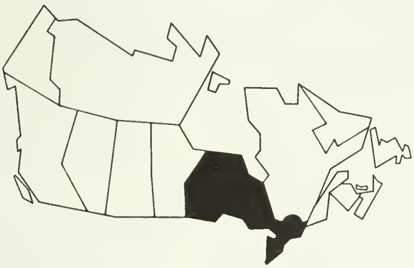

CANADA/ONTARIO

HYDRAULIC SYSTEMS

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HYDRAULIC SYSTEMS

FLUID POWER

The term "fluid power" refers to the channeling of fluids to do work.

Fluid can be any material capable of flowing, but is usually understood to be a liquid or a gas (including air). The main difference between a liquid and a gas is that gas can be compressed whereas a liquid cannot noticeably be compressed.

Fluid power encompasses both hydraulics and pneumatics. Hydraulics is fluid power using liquid, usually oil, to transmit power. Pneumatics is fluid power using gas, usually air, to transmit power.

Hydraulics is a means of power transmission only, it is not a source of power. Some source of power such as an engine, electric motor or manual pump is necessary to provide the initial power for a hydraulic system.

This publication will deal with oil hydraulics only and particularly its use and operation on farm tractors and machinery. It is intended to give the user and operator of hydraulic equipment a practical understanding of the principles involved, and should help him to maintain and operate his equipment for maximum efficiency.

Metric System of Measurement

This publication conforms to the International System of Units (SI units) which is the approved method of measurement to be used in Canada. Since Canada is in a transitional period regarding the metric system the following explanation of some of the terms used in this publication may be helpful.

Pressure Pressure in liquids and gasses is expressed in pascals (Pa). Since the pascal is a measure of an extremely small amount of pressure, the term kilopascals (kPa) meaning 1000 pascals is used in hydraulic systems. This replaces the term 'pounds per square inch (psi)' formerly used.

Mass Referred to in grams (g) or kilograms (kg) meaning 1000 grams, replaces former measures of weight such as pounds or ounces.

Force Force is expressed in newtons (N) and replaces the former term 'pounds force'. Force is a measure of the earth's gravitational pull on a mass which would cause it to accelerate.

Flow Flow is measured in litres per minute (L/min) which replaces the term 'gallons per minute'.

Complete conversion factors are listed on page 26.

PRINCIPLES OF HYDRAULICS

Pascal's Law

Pascal's Law states that "pressure set up in an enclosed fluid, at rest, is transmitted equally and undiminished in all directions to every part of the restraining surfaces".

Figure 1 illustrates a mass of 100 kg (kilograms) supported by a piston with an area of 500 mm^2 (square millimetres). This mass creates a force on the piston which sets up a pressure in the oil of approximately 2000 kPa (kilopascals). This pressure of 2000 kPa is transmitted equally in all directions throughout the entire system and can be utilized or tapped off at any point in the system. (The calculation of pressure, force and area is explained on page 12 of this publication).

Multiplication of Forces

To illustrate the principles mentioned above, let us add a second piston to the system shown in Figure 1. This second piston will have an area of 5000 mm^2 as shown in Figure 2. Since the same pressure (2000 kPa), is applied to the entire system, there will be a pressure of 2000 kPa applied to each of the 5000 mm^2 of the larger piston, therefore, the larger piston can support 10 times the mass of the smaller one, in this example 1000 kg mass. Since the small piston has an area of 500 mm^2 and the large piston has an area of 5000 mm^2 the ratio of force multiplication is 10 to 1. We do not gain this mechanical advantage "free", however, as we will have to move the small piston 10 mm for every 1 mm of movement of the large piston.

Hydraulic Jack

If we add a few more items to the system in Figure 2, we will have a hydraulic jack as shown in Figure 3. To prevent the oil from just traveling back and forth between the two cylinders, two check valves are required. These are simply one-way valves that allow the oil to move in one direction only. When the small piston is pushed down by the hand-operated lever, the oil will push past check valve A and raise the large piston

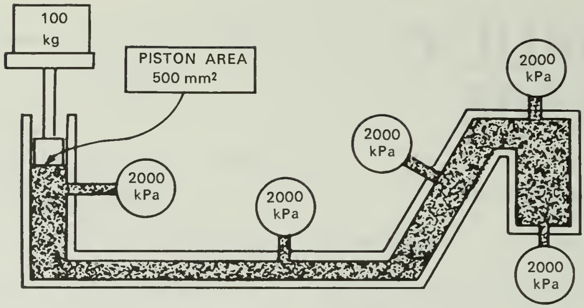

Figure 1 Pascal's law.

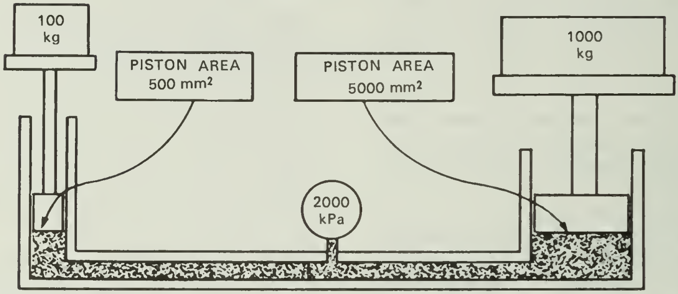

Figure 2 Multiplication of forces.

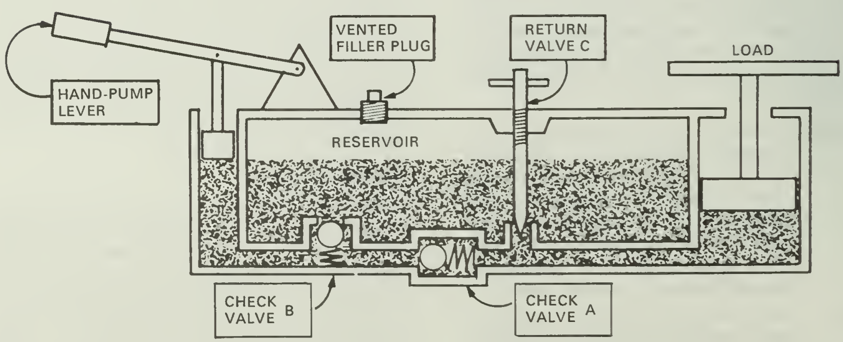

Figure 3 Hydraulic jack.

a short distance. To raise it further, the small piston is raised. Atmospheric pressure in the reservoir will push oil past check valve B to refill the small cylinder and make it ready for a second stroke. During that lifting stroke, check valve A retains the oil already in the large cylinder.

To lower the load, a third valve, C, is opened to allow the oil in the large cylinder to return to the reservoir.

The hydraulic jack is a complete hydraulic system. It has a pump, consisting of the small piston and two check valves, an oil reservoir, and a cylinder to raise the load.

HYDRAULIC PUMPS

A pump is a device that converts mechanical energy into fluid power energy. Pumps create flow; they do not create pressure. *The pressure at the output side of a pump will build up if, and only if, there is a resistance to the flow of oil from the pump.*

Pump Displacement

The displacement of a pump is a measure of the volume of oil displaced or moved in *one revolution* of the pump input shaft. Displacement is measured in millilitres (mL). Pumps may be classified as either positive or nonpositive displacement.

Nonpositive-displacement Pumps

These pumps propel fluid by means of the rotary action of an impeller. They are usually centrifugal pumps and are commonly used to circulate the coolant in water-cooled engines. They are nonpositive because the flow from the pump is not constant. As the resistance to the flow increases, the amount of flow decreases. A nonpositive pump is used only where very low pressures are present and the exact amount of flow is not important.

Positive-displacement Pumps

This is a pump that will always displace or move the same amount of oil during each revolution *regardless of speed or resistance*. The flow from a positive-displacement pump must not be blocked completely or a pressure will build up indefinitely until the pump housing bursts. It is positive-displacement pumps that are used on high-pressure hydraulic systems.

Pump Flow

The term "flow" is an abbreviation of the term "rate of flow" which refers to the volume of oil moved or pumped in a given period of time. This is measured in litres per minute (L/min). To calculate the flow from a pump, multiply the pump displacement by the r/min (speed of the pump in revolutions per minute). As an example, consider a pump with a displacement of 1.5 mL per revolution driven at 1000 r/min. The flow will be $1.5 \times 1000 = 1500$ mL/min.

The formulae for flow, displacement and r/min are as follows:

flow = displacement × r/min
displacement = flow ÷ r/min
r/min = flow ÷ displacement

Variable Positive-displacement Pumps

A variable-displacement pump is one where the output per revolution can be altered either manually or automatically. If a variable-displacement pump of a maximum displacement of 1 mL per revolution were driven at a speed of 1000 r/min it would be possible to vary the output from 0 to 1000 mL/min and hold it at any point between the two. These pumps may also be made reversible by mechanical controls (Figures 8 and 16).

Pressure-compensated Pumps

A pressure-compensated pump is a variable-displacement pump with a device that reacts to the system pressure. When a predetermined system pressure is reached at the pilot line, the pump is moved to its neutral position automatically, and its flow will be zero as long as the system pressure remains at maximum pressure (Figure 9).

Atmospheric Pressure

The air around us is under pressure at all times. This pressure varies according to altitude. The standard atmospheric pressure equals 101.325 kPa at sea level. For most calculations this can be rounded to 100 kPa. When air pressure is reduced below atmospheric pressure, it is said to be a vacuum. A perfect vacuum is created when all air is removed, and the pressure reduced to zero.

Gauge Pressure and Absolute Pressure

An ordinary pressure gauge shows the pressure level above that of atmospheric pressure. An unconnected gauge reads zero when, in fact, it is subjected to atmospheric pressure. The pressure gauges are calibrated this way for convenience and simplicity; however, some highly scientific gauges are calibrated to show atmospheric pressure as well. These are called "absolute pressure gauges" and the pressure is calibrated in absolute pressure. An absolute pressure gauge, when unconnected, will show atmospheric pressure, approximately 100 kPa.

Pump Inlet and Supply

A pump is supplied with oil by its being forced into the pump's inlet port by atmospheric pressure acting on the oil in the reservoir. As the pump rotates, it lowers the pressure at its inlet port below that of atmospheric pressure, creating a partial vacuum in the inlet line. Since fluid will always move from a high-pressure area to a low-pressure area, a flow is set up. Therefore, it can be said that oil is pushed, not drawn, into a pump by atmospheric pressure.

It is for this reason that the inlet lines to a pump are extremely important to the operation of that pump. The size of the inlet line must be proportional to the size of the pump so that there will be no unnecessary resistance to the flow into the pump from the reservoir. If the inlet lines are restricted in any way, the pump cannot receive the volume of oil it requires because atmospheric pressure is very limited and cannot overcome undue resistance. The problems that occur at the inlet side of the pump are discussed on page 24 under "Tracing Hydraulic Troubles."

Hydraulic Hose and Plumbing

The size of a pressure line is limited by the pressure loss created in the system due to friction. The accompanying chart (Table 1) is a guide to selecting the minimum line sizes. Be sure that all lines and fittings used on the high-pressure side of the system are rated as high as the relief-valve setting on the system. Never use galvanized pipe on any part of a hydraulic system, as the galvanizing will contaminate the oil and damage close-fitting parts.

To Calculate Hydraulic Line Sizes Velocity of the fluid through the lines is the limiting factor in selecting line sizes. Inlet or suction lines which operate at a low pressure must not have a fluid velocity greater than 1.25 metres per second. Pressure lines should not have a fluid velocity greater than 4.6 m/s. To calculate line sizes use the following formula or refer to Table 1.

Pipe cross-sectional area = flow divided by velocity.
(for velocity use either 1.25 m/s or 4.6 m/s as explained above).

External-gear Pumps

External-gear pumps (Figures 4 and 5) operate on a simple principle that as gears revolve, fluid trapped between the gear teeth and housing (A, Figure 4) is carried from the suction side (inlet) into the discharge side (outlet B). Since there is no room for the oil to go between the two gears at C, the oil is forced out through the outlet port. One gear is driven, the other follows. Timing of these gears is not necessary.

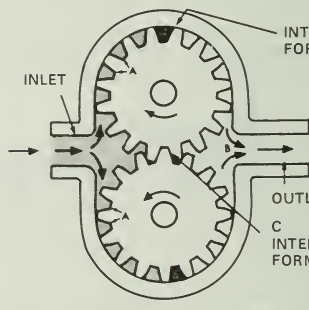

Figure 4 Diagram of external-gear pump.

TABLE 1. HYDRAULIC LINE — SELECTION CHART

Nominal Inside Diameter of Hose or Pipe		Inlet Line Maximum Flow	Pressure Line Maximum Flow
Inch Size	Metric *	Litres/Minute	Litres/Minute
¼ inch	6.4 mm	2.5	9
⅜ inch	9.5 mm	5.5	20
½ inch	12.7 mm	10	35
⅝ inch	15.9 mm	15	55
¾ inch	19 mm	22	80
1 inch	25.4 mm	40	140
1¼ inch	32 mm	60	220
1½ inch	38 mm	90	315

*It is not known if all these sizes will be available.

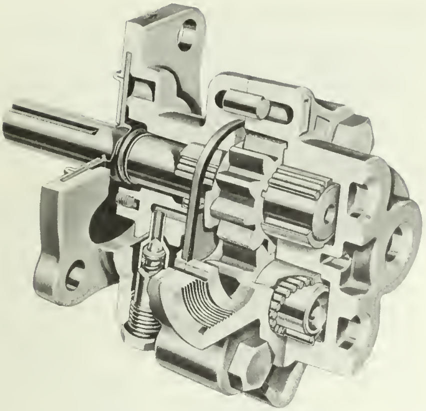

Figure 5 **Cutaway of external-gear pump, showing the outlet side. This pump has a built-in pressure relief valve.**

Internal-gear Pumps

Internal-gear pumps have one gear inside another. There are several versions of internal-gear pumps, including the rotary type, gerotor and orbital pumps and motors.

In the gerotor pump shown (Figure 6), the internal gear ring rotates within a close-fitting housing, carrying oil with it between the gear lobes. The spur gear that drives the gear ring must have one less tooth on it than the internal gear. The tooth form of each gear is related to that of the other in such a way that each tooth of the inner gear is always in sliding contact with the surface of the outer gear.

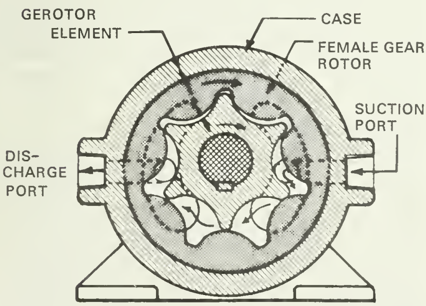

Figure 6 **Gerotor pump.**

These pumps may run more quietly than a comparable external-gear pump but they are very easily damaged or seized by any dirt that may pass through the pump.

Gear pumps are always of the positive-displacement type and cannot be of the variable-displacement type. The efficiency of gear pumps is largely determined by the close fit of the gears in relation to the housing. It is most important that the oil be kept clean, as any particles of dirt would wear grooves between the gear teeth and housing, reducing the efficiency of the pump.

Vane Pumps

The vane pump consists of a rotor (Figure 7) with a series of slots in it. The rotor is the driven member of the pump. In the slots are flat vanes that are free to slide in and out of the slots.

In the pump illustrated, the rotor rotates clockwise and the vanes ride out against the walls of the housing. As the rotor rotates, the open area in front of any one vane will change from a large volume to almost no volume. Oil entering these open areas at D will be carried around to the outlet area E. Since the area is getting smaller at this point and since oil cannot be compressed, the oil is forced out of the outlet.

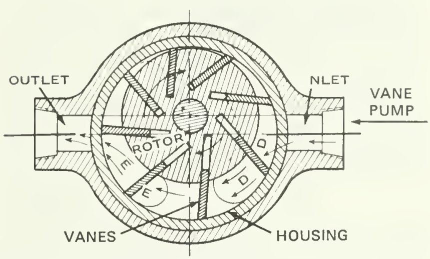

Figure 7 **Unbalanced vane pump.**

The vanes in a vane pump are kept out against the housing by any or all of the following methods:

1. Oil pressure from the outlet side of the pump may be directed into the slots behind the vanes, forcing the vanes out.
2. Centrifugal force will tend to keep the vanes out against the housing in the case of high speed pumps.
3. Springs are sometimes installed in the slots behind the vanes to keep them out tight against the housing.

Normal wear does not greatly reduce efficiency because the vanes will move further out in their slots to maintain contact with the housing. Dirt and sludge in a vane pump will cause the vanes to stick in their slots and seriously affect operation.

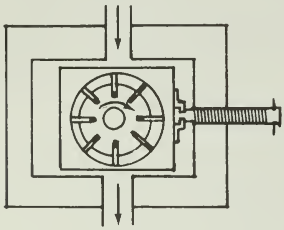

Figure 8 **Variable-displacement vane pump. The manually operated control changes pump displacement.**

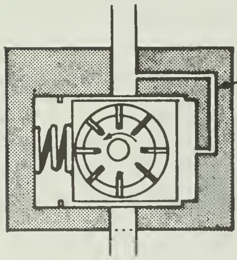

Figure 9 **Pressure-compensated vane pump. This will stop pumping when a predetermined pressure is reached.**

Unbalanced Vane Pump

This pump is said to be unbalanced as there is a heavy pressure loading on the outlet side of the pump shaft that does not exist on the inlet side. The advantage of this type of pump, however, is that it can be made variable as in Figures 8 and 9.

Variable Vane Pump

Figure 8 shows a vane pump where the piston of the ring housing can be varied mechanically by an operator while the pump is running. This changes the pump displacement from zero to full-flow in either direction.

Pressure-compensated Pump

Figure 9 illustrates a similar pump except that the ring housing is moved by hydraulic pressure acting against a spring. This pump, therefore, will move into a neutral, no-flow position when a predetermined pressure is reached.

Balanced Vane Pumps

The vane pump shown in Figure 7 is an unbalanced pump because there is a heavier pressure load on one side of the shaft than the other. The balanced vane pump (Figure 10) has two inlets and two outlets, each 180° opposite to each other so that the pressure loading holds the shaft in a state of balance. The elliptical-shaped housing allows two pumping cycles to take place simultaneously, which increases the pump displacement in proportion to its size.

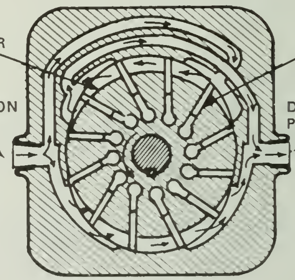

Figure 10 **Balanced vane pump.**

Piston Pumps

There are several types of piston pumps in use, the simplest being the reciprocating type illustrated in Figure 3 on the hydraulic jack. Power-driven piston pumps usually involve more than one piston to provide smoother operation, just as a gasoline engine uses a multiple of cylinders to add smoothness and power to the performance of the engine.

Axial Piston Pump

Axial piston pumps are pumps where the pistons travel parallel to the driving axle of the pump. Two types of axial piston pumps are shown. Figure 11 illustrates a swashplate type of pump with check valves. The cylinders are located in the main body of the pump and the swashplate is rotated to move the pistons in and out. Figure 12 shows an axial piston pump with cylinders located in a revolving barrel which rides against a port

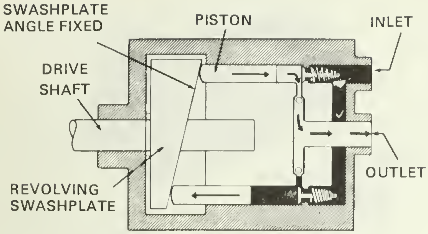

Figure 11 **Axial piston pump, revolving swashplate style.**

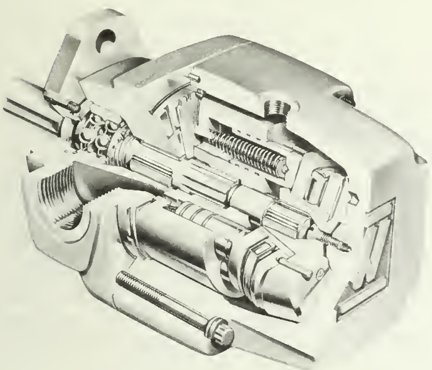

Figure 12 **Axial piston pump, revolving cylinder-block style.**

plate. The pistons ride against a thrust bearing set at an angle. The degree of angle of this thrust bearing will determine the displacement of the pump. The pump shown in Figure 12 has a fixed angle at its thrust bearing; however, the same type of pump is shown inside the hydrostatic transmission (Figure 16) with a variable thrust plate which converts the pump to a variable displacement-pump by adjusting the length of piston stroke.

Radial Piston Pump

A radial piston pump (Figure 13) has the pistons arranged in a direction following the radius of the driving shaft. This pump, like the axial piston pump, can be of either fixed-displacement or variable-displacement design.

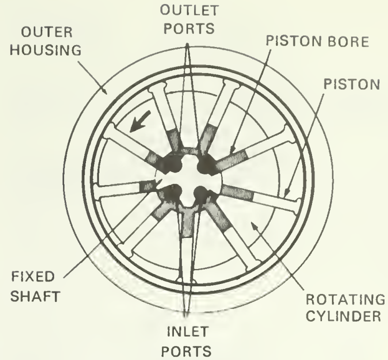

Figure 13 **Radial piston pump.**

HYDRAULIC MOTORS

A hydraulic motor converts hydraulic pressure and flow into a useable mechanical power just as an electric motor turns electric current into a useable mechanical power.

A hydraulic motor is basically the same as a hydraulic pump. In fact, many hydraulic pumps can be used as hydraulic motors.

Like pumps, hydraulic motors can be of the gear, vane, or piston types. The main difference is that a pump is driven by a source of power such as an engine which converts mechanical power to a fluid power; a hydraulic motor is driven by a fluid power which converts that power back to a mechanical power.

Figure 14 shows an external-gear motor. Oil pressure is applied to the inlet port and, as we know from Pascal's Law, an equal pressure will be applied to all surfaces of the gear teeth that are exposed to the inlet area. Therefore, there will be an equal force on both sides of the teeth marked "A," but the teeth marked "B" have only one side exposed to pressure, so they will be pushed by the pressure in the direction of the arrows. It can now be seen that both gears are driven in opposite directions by the applied pressure. The oil is trapped in the teeth and carried around to the outlet port where it is returned to the reservoir.

Figure 15 is a balanced vane motor. Vane motors must have some means of holding the vanes against the ring as, unlike a vane pump, centrifugal force will not hold them out. The unit shown uses springs behind the vanes.

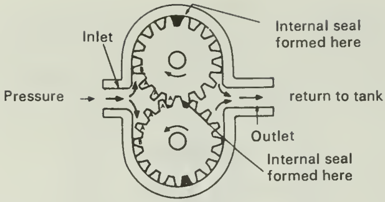

Figure 14 External gear motor.

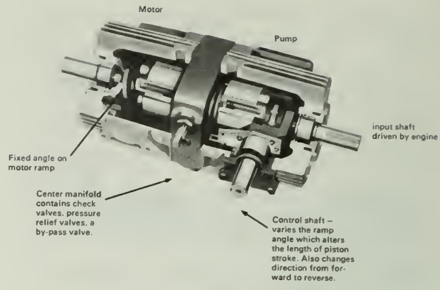

Figure 16 Hydrostatic transmission.

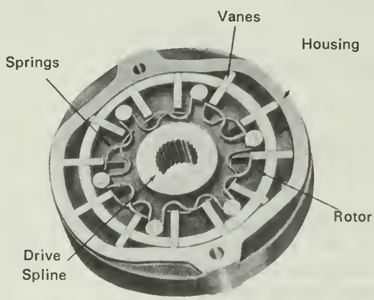

Figure 15 Vane motor.

HYDROSTATIC TRANSMISSIONS

Hydrostatic transmissions transfer power from a power source to a driven element without the need for a mechanical clutch or a series of gear reductions as used in a mechanical transmission.

A hydrostatic transmission is the coupling of a fluid pump to drive one or more fluid motors. A hydrostatic transmission may be a self-contained unit (Figure 16) or it may be built with the pump in one location and the motor or motors in another location connected by high pressure tubing. Either way the systems include check valves, pressure-relief valves, and a reservoir as the transmission must be a complete hydraulic circuit.

Most hydrostatic transmissions use a variable displacement reversible pump of either a vane or piston design. The motor can be either fixed displacement or variable depending on the torque and speed requirements of the unit; Figure 16 shows a hydrostatic transmission using a variable-volume piston pump with a manually operated control to change the angle of the thrust bearing from neutral to maximum displacement in either direction. The motor in this unit is a fixed-displacement piston motor.

When the control lever is turned a little the piston in the pump will travel a short stroke, delivering a small flow of oil to the motor pistons, thus causing the motor to turn at a slow speed. As the control lever is turned further, the piston stroke is increased, pumping more oil and driving the motor faster. This provides an infinite number of speeds in either direction without any steps between speeds, as in a mechanical transmission.

HYDRAULIC CYLINDERS

The hydraulic cylinder is by far the most popular method of utilizing fluid under pressure as a work force.

The two main classifications of cylinders are single acting and double acting. Single-acting cylinders (Figures 17 and 18) use hydraulic force to extend the cylinder and lift the load, but the piston must be retracted by gravity or springs. Double-acting cylinders (Figures 19 and 20) use hydraulic pressure both to extend and retract the cylinder.

Single-acting Cylinders

Single-acting cylinders may be of the piston type or ram type. The piston-type cylinder shown in Figure 17 is typical of the cylinders built into the rear lift system of tractors. Many piston-type, single-acting cylinders are of the same construction as the double-acting cylinder (Figure 19), except that only one inlet port is used for oil, and the other used as an air vent.

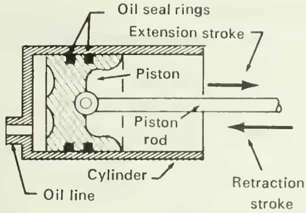

Figure 17 **Single-acting hydraulic cylinder.**

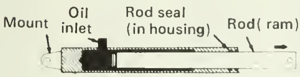

Figure 18 **Ram-type cylinder.**

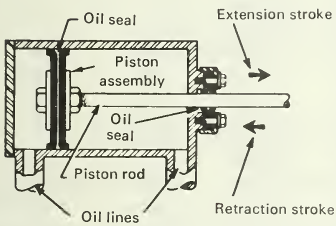

Figure 19 **Double-acting hydraulic cylinder, differential type.**

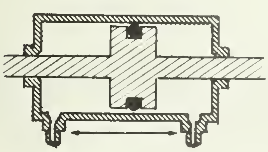

Figure 20 **Double-acting hydraulic cylinder, equal- operating type.**

The ram-type cylinder (Figure 18) has no piston and only the end of the rod is affected by oil pressure, which forces the rod to move out of the enclosed cylinder. These are very simple cylinders and, since no precision machining is required on the inside of the cylinder walls, it is an inexpensive cylinder. The only defects a ram cylinder can have is if the end seal or bushing is worn, which would allow external oil leakage.

Double-acting Cylinders

Double-acting cylinders may be of the differential type (Figure 19) or equal operating type (Figure 20). The differential cylinder is the most common type of hydraulic cylinder in use. It is both extended and retracted by hydraulic pressure; however, since the piston rod extends from one end of the piston, there is less area remaining on that end to receive the effect of the pressure. Therefore, in operation, the differential cylinder can apply a greater maximum force on the extending stroke than on the retracting stroke. (The maximum force of any cylinder is limited by the setting of the system pressure-relief valve.)

The speed of operation of a differential cylinder also varies from extending to retracting stroke. When the pump flow is constant, the cylinder will retract faster than it extends.

The equal-operating cylinder (Figure 20) has a rod extending from both ends of the piston; therefore, in operation, both the maximum force and speed are identical on extending and retracting.

Special Cylinders

When two or more hydraulic cylinders are connected in series, a special valve is located in the pistons to allow oil to reach the lines between the cylinders. Ordinary cylinders cannot be used in series.

Other special cylinders include cushion devices, speed controls, fast approach and telescoping. Details on these special cylinders are available from the manufacturers.

Seals and Packings

All hydraulic cylinders must have some form of piston ring or seal to prevent the oil from forcing its way past the piston when under load. Double-acting cylinders must also be sealed where the rod passes through the cylinder end.

There are many types of seals in use. Figure 17 shows the use of alloy steel rings on the piston, and Figure 19 shows the use of leather or synthetic seals. Perhaps the most popular seal in use in farm and industrial equipment is the "O" ring (Figure 20).

When a cylinder, pump or valve is disassembled for any reason, always replace all oil seals with new ones. While the seal may not have been leaking before disassembly, it will probably leak after removing and replacing. It is also important to check the shafts and cylinder walls for scoring or pitting.

TABLE 2. CYLINDER CALCULATING CHART

Values shown are for single-acting cylinders or differential cylinder extending stroke. For retracting stroke deduct the area of the rod from the area of the piston first.
For cylinder speed, multiply speed shown by litres per minute flow to cylinder.

Piston or rod diameter (mm)	Piston or rod area (mm^2)	Maximum force and lifting capacity at pressures shown						Speed of cylinder for one litre per min flow (mm/s)
		5 000 kPa		10 000 kPa		15 000 kPa		
		force (kN)	mass (kg)	force (kN)	mass (kg)	force (kN)	mass (kg)	
10	80	0.382	39	0.764	78	1.146	117	213
15	180	0.862	88	1.724	176	2.587	264	95
20	310	1.538	157	3.077	314	4.616	471	53
25	490	2.401	245	4.802	490	7.203	735	34
30	710	3.459	353	6.919	706	10.378	1 059	24
35	960	4.713	481	9.427	962	14.141	1 443	17
40	1 260	6.154	628	12.308	1 256	18.463	1 884	13
45	1 590	7.791	795	15.582	1 590	23.373	2 385	10
50	1 960	9.604	980	19.208	1 960	28.812	2 940	8.5
55	2 370	11.637	1 187	23.275	2 375	34.912	3 562	7.0
60	2 830	13.852	1 413	27.704	2 827	41.557	4 240	5.8
65	3 320	16.258	1 659	32.516	3 318	48.774	4 977	5.0
70	3 850	18.865	1 925	37.730	3 850	56.595	5 775	4.3
75	4 400	21.560	2 200	43.120	4 400	64.680	6 600	3.8
80	5 020	24.500	2 500	49.000	5 000	73.500	7 500	3.3
85	5 670	27.807	2 837	55.615	5 675	83.422	8 512	2.9
90	6 360	31.164	3 180	62.328	6 360	93.492	9 540	2.6
95	7 080	34.692	3 540	69.384	7 080	104.076	10 620	2.3
100	7 850	38.465	3 925	76.930	7 850	115.395	11 775	2.1
110	9 500	46.550	4 750	93.100	9 500	139.650	14 250	1.8
120	11 300	55.370	5 650	110.740	11 300	166.110	16 950	1.5
130	13 270	65.023	6 635	130.046	13 270	195.069	19 905	1.2
140	15 400	75.460	7 700	150.920	15 400	226.380	23 100	1.0
150	17 670	86.583	8 835	173.166	17 670	259.749	26 505	0.9

Calculating Cylinder Force, Pressure and Area

The force of a cylinder (measured in newtons) or the lifting capacity (mass) depend on two factors: (1) the amount of pressure available that can be applied to the piston in the cylinder (2) the size or area of the piston exposed to the pressure.

Figure 2 showed how an applied load of 100 kg on a piston with an area of 500 mm^2 set up a pressure of 2000 kPa. Since the mass of 100 kg is exerting a force on the piston due to gravitational pull there is said to be a force of approximately 1000 newtons(N). The more exact force created by 100 kg mass is 980 N. (The international standard gravity exact value is 9.80665 m/s^2). To find the exact force created by any mass, multiply the mass (in kilograms) by 9.8. For most calculations relating to hydraulic systems this value (9.8) may be rounded to 10 for easy calculation. The following formulae use the value 10 rather than 9.8 as this is well within reasonable accuracy for hydraulic systems.

Formulae The basic formula for sizing hydraulic cylinders may be expressed in these three ways:–

$$\text{Force} = \text{Pressure} \times \text{area.}$$

$$\text{Pressure} = \frac{\text{Force}}{\text{area}}$$

$$\text{Area} = \frac{\text{Force}}{\text{pressure}}$$

To convert force in kN to mass in kilograms, multiply the force (kN) by 100.

To calculate *the size of cylinder* required to move a certain mass (the load on the cylinder) use this formula:

$$\text{area } (mm^2) = \frac{\text{mass (kg)} \times 10\,000}{\text{pressure (kPa)}}$$

To calculate the *pressure* required to move a certain mass use this formula:

$$\text{pressure (kPa)} = \frac{\text{mass (kg)} \times 10\,000}{\text{area (mm}^2\text{)}}$$

To calculate the *mass* (load) that can be moved by a certain cylinder with a fixed maximum pressure use this formula:

$$\text{Mass (kg)} = \frac{\text{pressure (kPa)} \times \text{area (mm}^2\text{)}}{10\,000}$$

Calculating Cylinder Speed

The rate of travel of the cylinder shaft depends on the flow rate (L/min) and the area of the cylinder piston. As a differential cylinder will retract faster than it will extend, the "rod end area" must be used when calculating the retracting speed.

To calculate the cylinder speed or *velocity*, use the formula:

$$\text{velocity (mm/s)} = \frac{\text{flow (L/min)} \times 1\,000\,000}{\text{area (mm}^2\text{)} \times 60}$$

To find the flow required to achieve a certain velocity:

$$\text{flow (L/min)} = \frac{\text{velocity (mm/s)} \times \text{area (mm}^2\text{)} \times 60}{1\,000\,000}$$

To find the area when the velocity and flow are known:

$$\text{area (mm}^2\text{)} = \frac{\text{flow (L/min)} \times 1\,000\,000}{\text{velocity (mm/s)} \times 60}$$

Area and circle formulae

area of a circle = radius squared × 3.1416
or diameter squared × 0.7854
volume of a hydraulic cylinder = area of piston × stroke

Formulae for power requirement of a pump

$$\text{power (kW)} = \frac{\text{pump flow (L/min)} \times \text{pressure (kPa)}}{50\,000}$$

$$\text{flow (L/min)} = \frac{\text{power (kW)} \times 50\,000}{\text{pressure (kPa)}}$$

$$\text{pressure (kPa)} = \frac{\text{power (kW)} \times 50\,000}{\text{flow (L/min)}}$$

HYDRAULIC VALVES

Valves are mechanical devices that regulate pressure, direction, volume, and flow of oil in a hydraulic system.

Pressure-relief Valves

Pressure-relief valves are used to protect a hydraulic system just as a fuse protects an electrical circuit.

The section on hydraulic pumps (page 5) discussed positive displacement pumps which will displace a certain amount of oil for each turn of the pump. The pressure at the output side of a pump will build up only if there is a resistance to the flow of oil from the pump. Since the pump has a positive displacement, the pressure will build up without limit if the resistance is strong enough. Therefore, a point would be reached where the pressure would be too great for the pipes and fittings or even for the body of the pump itself to contain and some part of the system would burst. To prevent this, a pressure-relief valve is built into all hydraulic systems.

A pressure-relief valve may be of a preset or adjustable-pressure design but either type performs the same function: it limits the maximum pressure that can be built up at any point in the hydraulic system.

Direct-acting (simple) Relief Valves

These valves allow the pressure to be sensed at a ball or piston which is normally held shut by a strong spring (Figure 21). The adjustment screw alters the tension of the spring which will then require more, or less, pressure to unseat the ball. When the pressure in the system exceeds the tension of the spring, the oil returns to the reservoir through the return port. Simple relief valves are suitable only for systems operating at relatively low pressures or low flows.

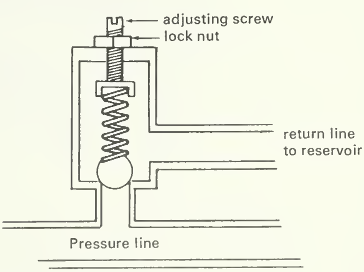

Figure 21 Simple relief valve.

Pilot-operated Pressure-relief Valves

The pressure-relief valve must be able to allow the full flow of the system to pass through it. Using a direct-acting valve as shown in Figure 21,

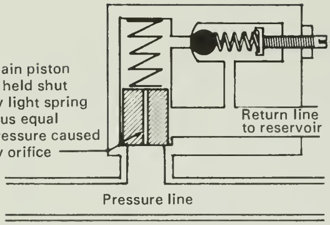

Figure 22 **Pilot-operated relief valve.**

the area of the ball exposed to the pressure would be fairly large to allow sufficient opening for large system flows. If the exposed area is large, the spring pressure would have to be proportionately large. As an example, if 300 mm^2 area of the ball or piston of a relief valve were exposed, to maintain a pressure of 15 000 kPa the spring would have to hold a load equivalent to a 450 kg mass. A spring that size would be much too large to fit into the hydraulic system (it would be about the size of the coil spring on an automobile wheel suspension). To overcome the need for these large springs, pilot-operated valves are used.

Figure 22 shows that the main valve is held shut by both a light spring and hydraulic pressure sensed through the orifice. Therefore, any pressure increase will affect both sides of the main valve, holding it shut. When the pressure reaches the setting of the small pilot valve (which has a very small area exposed to pressure), it will open and allow a slight flow through the orifice to the reservoir. *When there is flow through an orifice, there is always pressure drop.* When this pressure drop exceeds the setting of the light spring, the main valve will open and allow the entire system flow to return to the reservoir.

Pressure-relief Valve Setting

Always refer to the manufacturer's specifications to find the correct system pressure and do not attempt to set a relief valve without a pressure gauge.

The setting of the pressure-relief valve is the most important adjustment on a hydraulic system. We know why the pressure must not be allowed to build too high; now let us consider the effect of too low a setting on a relief valve. The pressure in the system can never build up higher than the relief valve setting; therefore, if the setting is too low the hydraulic system cannot do the amount of work it was designed to do. Another effect of undersetting a relief valve is that the oil will be running over the valve for longer periods than normal, creating heat in the system which can damage the seals and fittings.

To set an adjustable pressure-relief valve, a pressure gauge *must* be installed in the system on the outlet (pressure side) of the pump. With the unit running, fully load the system. If the system contains a hydraulic cylinder, run the piston all the way to the end and leave the control valve engaged so that the pressure will build up and open the relief valve. Observe the pressure reading when the relief valve is opening and, if it is incorrect, adjust it by turning it to the right to raise the pressure or to the left to lower the pressure.

Flow-divider Valves

To split the flow of fluid in an ordinary plumbing system, a common tee is used in the pipes. In a hydraulic system when two or more different applications are in use at one time, a common tee would be inadequate as the flow would always go to the side with the least resistance. Therefore, a flow-divider valve is used. It is, in effect, a tee with the addition of a built-in pressure balancing device which will split the flow as required, regardless of the pressure at each side. There are two types of flow dividers—proportional and priority.

Proportional Flow Divider

When the flow from the pump is to be divided at a set proportion, usually 50-50, a proportional flow divider is used. In the valve shown, (Figure 23) the spool is free to move toward the side with the least pressure. If the pressure increased at outlet Number 1, the tendency would be for the oil to flow out of Number 2 outlet (since oil will always take the path of least resistance). However, the increased pressure at the right side of the spool will move the spool to the left, restricting outlet Number 2. This prevents any increase in flow through Number 2 outlet, thereby maintaining equal flow through each port regardless of pressure.

Priority Flow Divider

Many systems require a set amount of oil to be split off from the main flow to supply a separate system, such as power steering. This means that if the priority flow were to be 10 L/min the priority port would receive 10 L/min regardless of the total flow in the system. All of the flow over the above the 10 L/min is bypassed.

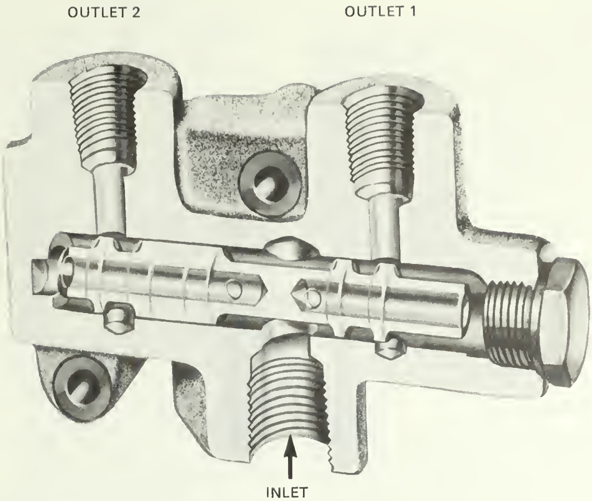

Figure 23 **Proportional flow divider.**

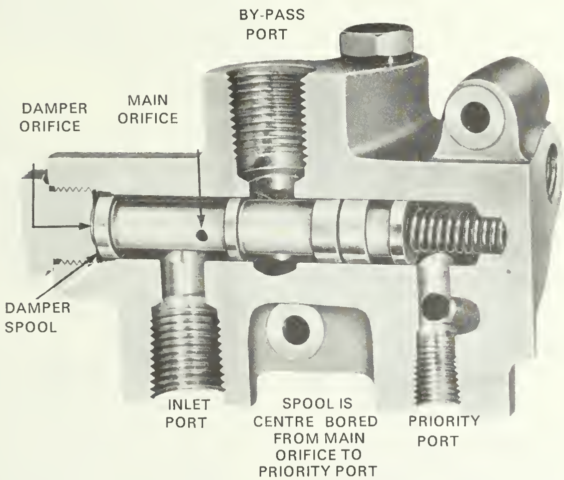

Figure 24 **Priority flow divider.**

Figure 24 illustrates a priority flow divider. The spool is held to the left by the spring, and the inlet flow attempts to pass through the main orifice in the spool to the priority outlet. However, as the flow increases through the orifice, the pressure difference created by the flow will create a higher pressure on the left end of the spool than on the right end. When this pressure differential overcomes the resistance of the spring, the spool will move to the right and open the bypass port. Therefore, it is the tension on the spring that controls the amount of flow from the priority port. These valves may be equipped with an adjusting screw on the spring to regulate the priority flow.

Vibration Damper

Many valves utilize a damper orifice (Figure 24). This prevents the valve spool from vibrating by simply trapping some oil in the end of the valve spool and allowing it to pass in and out of a chamber through a very small orifice. This is a similar principle to that used on shock absorbers on automobiles. The oil will only pass through the orifice slowly and therefore prevents the valve spool from vibrating. This small orifice can become blocked by dirt, which would cause the valve to be locked either open or closed. If a valve becomes inoperative, check for a blocked orifice in the damper.

OPEN- AND CLOSED-CENTER SYSTEMS

Unloading the Pump

Since the pumps used on tractors, farm machinery and mobile equipment run constantly as long as the engine is running, it is necessary to "unload" these pumps when they are not in use, so that the pump is not working hard during the neutral period. The pump may be unloaded in either of two ways: pressure or flow. If the pump is a fixed-displacement type, the flow must be allowed to run free when not in use. This is done by unloading the pressure and permitting free flow back to the reservoir when the valve is in neutral. If the pump is a pressure-compensated type, as in Figure 9, the flow can be unloaded and the pressure maintained.

The above-mentioned methods of unloading the pump are determined by the type of control valve and the type of pump. The following definitions should help you understand the two systems:

1. An open-center system in neutral has full flow but no pressure.

2. A closed-center system in neutral has full pressure but no flow.

Directional Control Valves

Directional control valves are the switches of a hydraulic system. They allow the flow of oil to be switched from one cylinder to another, to raise and lower cylinders, or to direct the flow of oil to run a hydraulic motor. Control valves are usually of the rotary or spool type.

The control valve must be tailored to suit the system it is used with, since the valve must perform several functions in addition to controlling the various components of the system. One of these functions is the unloading of the pump.

Control valves are described by the type of "center" in the valve and by the number of functions the valve performs. The "center" refers to the flow path through the valve when it is in the neutral or non-working position. A valve may be described as open center, closed center or tandem center. If the valve has four working ports, it is said to be a four-way valve. The four working ports would be (1) a pressure or inlet port, (2) return to reservoir port, (3 & 4) two cylinder or motor-operating ports. A three-way valve usually has an inlet port, return to reservoir port and just one cylinder or motor-operating port.

Spool Valves

Directional control valves may be of either a rotary or spool design; however, spool valves (Figure 25) are by far the most common in use on farm machinery as they are easily grouped together for multiple-valve applications (Figure 26).

The design of the spool within the valve determines the type of valve center and the flow path in each of the valve positions. The following illustrations of spool valves are all illustrated in the same valve body; only the design of the spool is changed to provide the various functions.

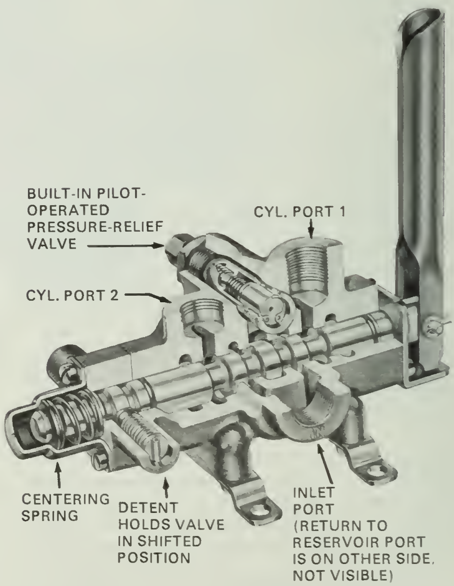

Figure 25 Typical spool valve with tandem-center spool.

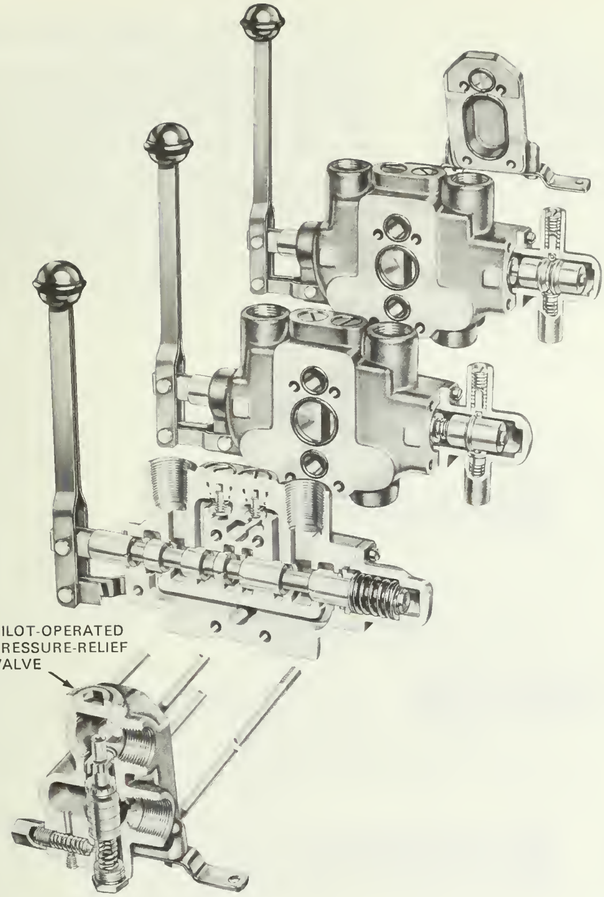

Figure 26 Multiple-spool valves.

Open-center Valve

Figure 27 illustrates an open-center valve in neutral position. Since this is a fully open-center valve, all of the four ports are open to each other when the valve is in neutral. This allows the pump flow to return to the reservoir without restriction, and the two working ports to pass oil freely in or out. This type of valve is usually used for controlling hydraulic motors or cylinders where it is not desirable to lock the motor or cylinder in one place while the valve is in neutral. A fully open-center valve is often referred to as a "motor-center" valve, as it allows the attached hydraulic motor to coast or free-wheel while the valve is in neutral.

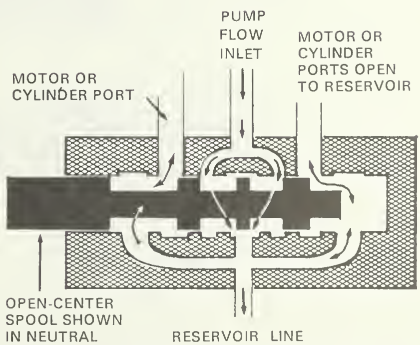

Figure 27 **Open-center spool valve. Unlike the tandem-center valve, the cylinder ports are open when the spool is in neutral. When activated, the flow is the same as for tandem-center valves.**

Tandem-center Valves

The tandem-center valve is the most common spool used for cylinder operation. It is similar to the open-center valve, except that the cylinder ports are blocked when the valve is in neutral in order to hold the cylinder in a fixed position. It is named tandem center because it incorporates two systems. The pump to reservoir flow is the same as an open-center valve but the cylinder ports are blocked, as in a closed-center valve. A hydraulic system, using a tandem-center valve, is referred to as an open-center *system* because the pump flow is free to return to reservoir when the valve is in neutral.

Figure 28 illustrates an open-center system using two tandem-center valves connected in series. Valve 1 is shown in neutral; the pump flow can pass right through the valve but the cylinder ports are blocked to hold the cylinder in a locked position. Valve 2 has been moved to the right, which directs the flow to the rod end of the cylinder, retracting it. The oil in the other end of the cylinder is allowed to return to the reservoir. If the spool were moved to the left, the cylinder would extend.

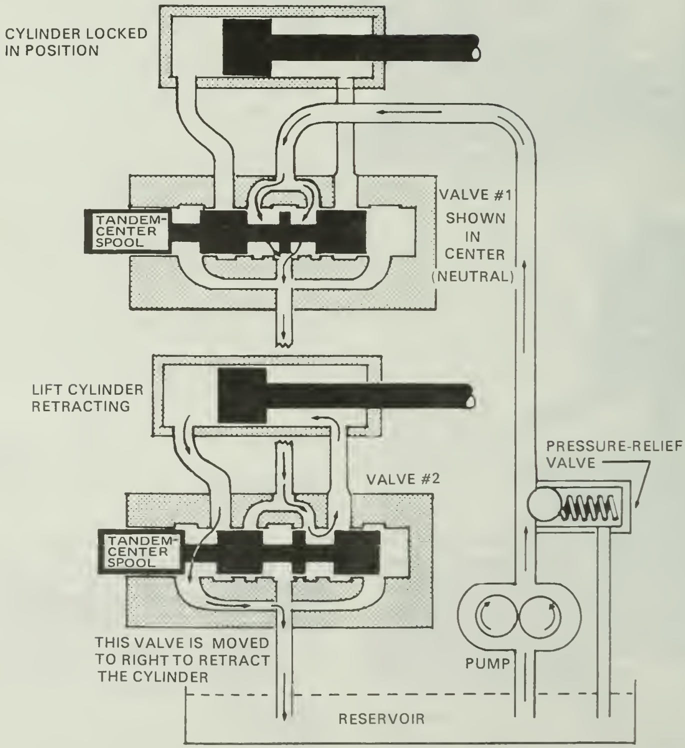

Figure 28 Open-center system using two tandem-center valves connected in series.

Closed-center Valve

The closed-center valve, when in neutral (Figure 29, Valve 2), has all its working ports blocked. There is no flow through the valve in any direction. Since this totally restricts the pump flow, the pump must be of the pressure-compensated type which reacts to the increase in pressure and moves its pistons or vanes out of stroke so that there is no flow in the system. With this valve in neutral, a high pressure is maintained in the line from the pump to the valve which provides very fast response when the valve is moved to a working position. Figure 29, Valve 1, shows the spool moved to the left, allowing the flow to extend the cylinder, and routing the return flow back to the reservoir. The two valves in Figure 29 are connected in parallel because they are closed center.

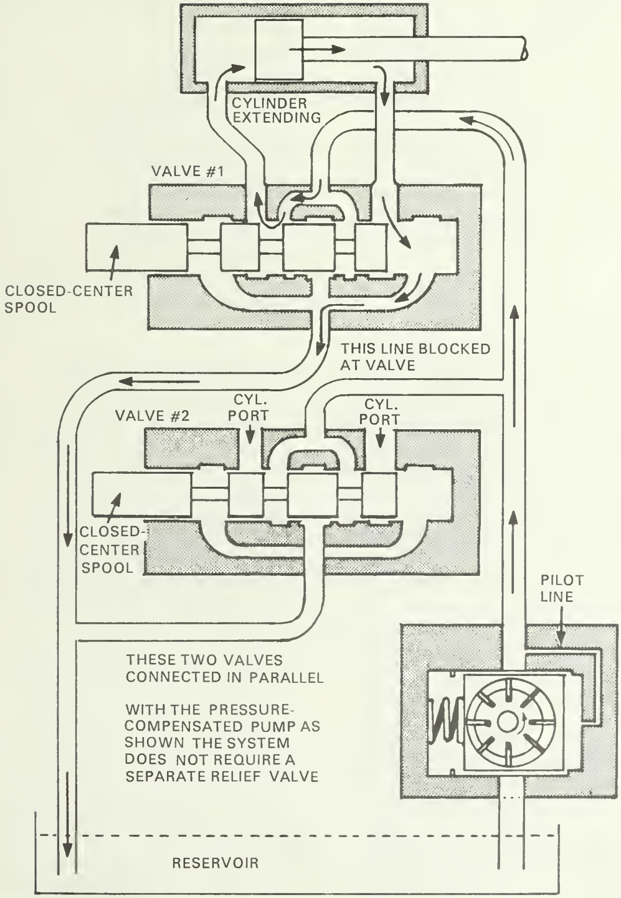

Figure 29 Closed-center system using pressure-compensated pump.

Multiple Valves

When a hydraulic system is required to operate more than one cylinder, the system is usually simplified by using a series of control valves built into one body, or several valve bodies bolted together to form one body (Figure 26). This saves space and prevents plumbing and leakage problems. In addition, many systems have the pressure-relief valves and check valves built into the same valve body.

Open-center Systems vs Closed-center Systems

Since an open-center system involves fewer parts and is less expensive, it is usually used on simple hydraulic systems with one or two cylinders.

On more complicated machinery and most modern farm tractors, the hydraulic system performs several different functions, often simultaneously. For this reason, closed-center systems are used more frequently as they give a quick response to any point in the circuit, and the pump is not working hard when the hydraulics are not in use.

Combined Open- and Closed-center Systems

Many hydraulic systems, particularly on tractors, combine a variety of systems to provide the most suitable features for each function the system must perform. Figure 30 is simply an example of how these various systems may be coupled together, all operating off one fixed-displacement pump. This system, from the pump through the flow divider to the power-steering system and through to the check valve, would be considered to be an open-center system because the pump flow is constant and is allowed to flow freely back to the reservoir when not in use. However, the system beyond the check valve, including the directional control valves, is a closed-center system which maintains a stationary high pressure in the lines when the valves are in neutral. This is possible because a check valve isolates the two systems and the unloading valve reacts to the pressure in the accumulator and diverts the pump flow back to the reservoir. When a control valve is moved, the pressure will drop off at the accumulator and the pilot line, at which time the spring in the unloading valve will move the valve back to the left, allowing the pump flow to push past the check valve and supply the system as well as recharge the accumulator. The accumulator in this system provides an extremely fast response when a control valve is moved.

ACCUMULATORS

An accumulator is a device that can store a quantity of oil under pressure and release it on demand. They are sometimes used to dampen pressure surges or shock loads generated within the system. A tire or balloon is an accumulator which stores air under pressure, but that is possible because air is compressible. Since oil is not compressible, it cannot be squeezed into a container smaller than its own volume. To store oil under pressure, it is necessary to use some other form of fluid that is compressible, such as a gas or air. Accumulators may also be spring loaded or weight loaded but these are not common on farm machinery.

By dividing the accumulator chamber with either a piston (Figure 30) or a bladder, the oil can be contained separately from the gas and yet the compressibility of the gas will keep the oil under pressure. As the oil is pumped into the accumulator, the gas is forced to compress; as the gas compresses, its pressure increases. Therefore, the pressure of the oil will also increase to balance the gas pressure. The pressure of the oil and the pressure of the gas will always be equal, since the free-floating piston or bladder will stay in balance between the two fluids.

Precharging Accumulators

The gas compartment of the accumulator may be precharged which provides a minimum pressure at which the accumulator will receive oil. The amount of precharge is determined by the particular use of the accumulator. Accumulators are precharged by using a pressure tank containing the correct gas required for the accumulator. The tank is connected to the accumulator and, using a pressure gauge, the gas is forced into the accumulator until the desired pressure is reached.

Caution: an accumulator can be dangerous. The correct gas must be used in an accumulator; this is usually dry nitrogen gas.

Never fill an accumulator with oxygen. A dangerous explosion could result if oil and oxygen mix under pressure.

Never fill an accumulator with air. Water vapor in the air will condense in the accumulator and cause rust and seizing.

Never charge an accumulator to a pressure above the manufacturer's specifications. An explosion could occur.

Never remove or repair an accumulator without first releasing both the gas and hydraulic pressures.

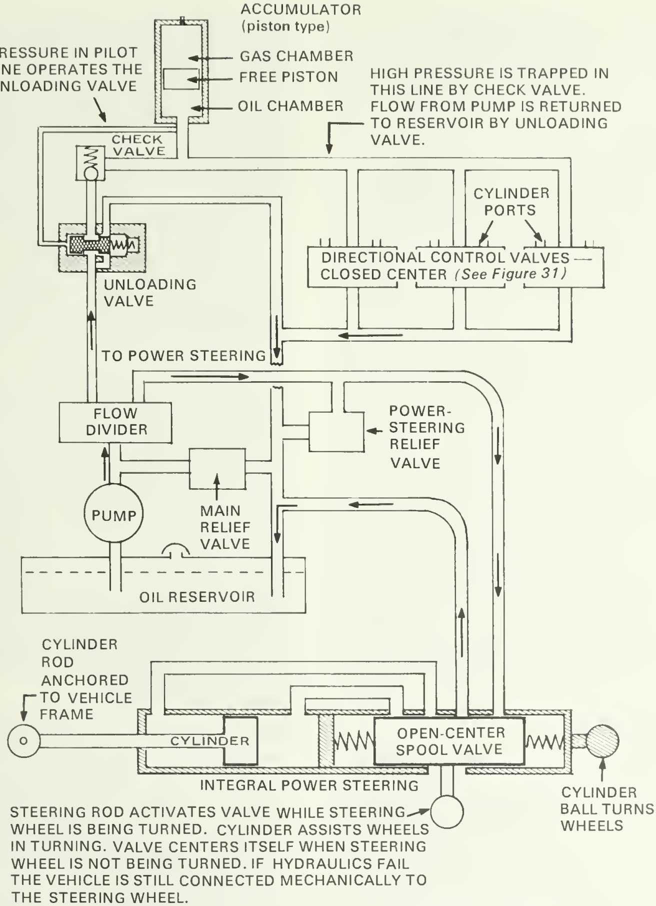

Figure 30 Typical hydraulic system combination of open- and closed-center systems.

TRACTOR REAR-LIFT SYSTEMS

Farm tractors use a three-point hitch system controlled by a combination of hydraulic and mechanical linkage. The control valves are operated both manually by the operator and automatically by a position-sensing or load-sensing device. These two sensing devices are known as "position control" and "draft control."

Position Control

Position control is sometimes referred to as constant-depth control. It is a method of holding the rear lift and its mounted equipment at a constant depth *in relationship to the tractor chassis*. The control valve that raises and lowers the rear lift is controlled from two points. First, it is connected to a hand-control lever moved by the operator through a quadrant (one quarter of a circle). Second, the same valve is controlled by a linkage that moves as the lift is raised or lowered. As the lift raises, the linkage will "override" the manual control and stop the lift at a position dictated by the position of the control lever in the quadrant. An adjustable stop is provided to serve as a "memory" so that the lever

can be returned to the same place each time without the operator actually watching the lever. The position of the rear lift will always correspond to the position of the control lever in the quadrant.

Draft Control

The term "draft" refers to the *resistance* of the implement to be pulled. "Draft control" is a device built into the tractor to raise or lower the implement, as necessary, to maintain a uniform draft or resistance. In draft control, as in position control, the valve that raises and lowers the rear lift is controlled from two points. First, it is connected to a hand control lever in a quadrant, and second, the valve is controlled by a load-sensing spring which overrides the manual control linkage. Some tractors use the same quadrant lever for both position and draft control, whereas others have separate control levers. The load-sensing spring may be connected to either the top link or bottom links of the three-point hitch, but either way it reacts to an increase or decrease in the implement draft. When the load starts to increase, the reaction on the sensing spring moves the control valve and raises the implement. The implement will raise only the amount necessary to resume the original resistance to the tractor. When the draft decreases, the spring relaxes and allows the implement to lower deeper into the ground.

Draft or Position Control — Which to Use?

Most farm tractors are equipped with both position and draft control for use with mounted attachments, but many tractor operators do not fully understand the two systems and consequently do not derive the full benefit from the equipment they are using. Let us consider the function and operation of the two systems when used to operate a fully mounted moldboard plow.

It must be remembered that position control maintains a constant relationship between the position of the rear lift and the tractor chassis. It does not sense the depth or draft of the plow in the ground. On level ground of uniform soil conditions, position control will maintain a uniform depth of plowing. On undulating or bumpy ground, with the lift in position control, the depth of plowing will vary as a reaction to the movement of the front wheels of the tractor over uneven ground. When the front wheels are raised, the plow at the rear of the tractor will go deeper into the ground; when the front wheels drop into a hole, the plow will react by raising, causing a shallow furrow. To overcome this problem on uneven ground, use draft control; with the draft-control mechanism in operation as the plow attempts to go deeper, because of the raising of the front wheels, the increased draft will cause the rear lift to raise in relation to the tractor, and thereby maintain a uniform depth of plowing. The plow will continue to raise and lower, as necessary, to maintain a uniform draft on the tractor.

The situation is more difficult to overcome on land where there are hard-pan conditions or changing soil conditions throughout a field. If draft control is used on this type of land, the plow will lift each time it approaches an area of hard-pan. This is because, in draft control, the lift responds to an increase in draft created by the harder plowing conditions. Many operators use draft control in these conditions because it makes it easier for the tractor to travel without any noticeable change in load or traction; however, it must be realized that the hard soil *is not being plowed* and, if draft control is used each season on the same land, the hard-pan will never be plowed. Therefore, on this type of soil condition, the result of plowing will be better if position control is used, not draft control, even though it may present some difficulty in hard-pan where the tractor may have to be geared down as necessary to pull the plow through the tougher soil.

Response Control

Many tractors are equipped with an adjustable control known as "response" or "speed" control for the rear lift. This valve is simply an adjustable-flow divider (Figure 24) built into the line that supplies oil to the lift cylinder. By splitting off some of the flow going to the lift cylinder, and diverting it back to the reservoir, the cylinder lift speed is slowed down. When the rear lift is in draft control, this will slow down the rate of reaction to changes in draft which is an advantage in some soil conditions, particularly on stony land where it is not desirable to have the plow lift every time it encounters a stone.

HYDRAULIC STEERING SYSTEMS (POWER STEERING)

Two major types of power steering are used on tractors and farm machinery: "power-assisted" steering and "full-power" steering.

Power-assist Steering In this system, the vehicle is equipped with normal mechanical steering with the addition of a hydraulic booster to help the operator turn the wheels. All automobile power steering is of the power-assist type. When

the steering wheel is turned, the initial movement of the linkage operates a hydraulic valve that directs the oil flow to a cylinder on the steering linkage. The valve will only remain in operation while the operator is applying effort to turn the wheel; when he stops turning, the valve centers itself and steering ceases. Figure 30 shows an integral steering cylinder and valve; other systems use a valve mounted separately to the cylinder and another variation has the cylinder and valve mounted in the housing of the steering gear.

The hydraulic system to operate the steering is usually part of the main tractor hydraulic system (Figure 30) or there may be a separate pump to supply the power steering only, as on an automobile.

Full-power Steering Full-power steering, often referred to as hydrostatic steering, provides no mechanical linkage between the steering wheel and the vehicle wheels. The steering of the vehicle is controlled completely by hydraulic power (Figure 31).

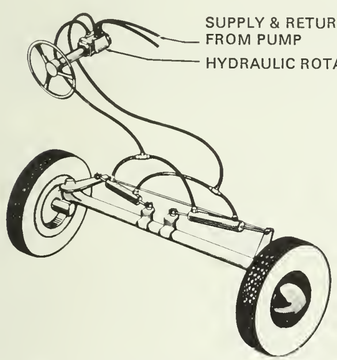

Figure 31 Full hydraulic steering.

The steering wheel is connected directly to a hydraulic pump-valve combination. As the driver rotates the steering wheel, the rotating valve directs fluid to the hydraulic cylinder connected to the vehicle's wheels. This valve requires continued light effort on the driver's part to keep the valve in operation. When the engine is not running, the pump-valve unit becomes a manually operated pump and directs the flow to a cylinder to provide steering.

HYDRAULIC FLUIDS

Functions of Hydraulic Fluid

First of all, it must be capable of transmitting the power applied to it. It must lubricate the internal moving parts of the pumps, cylinders, motors, and valves. It must serve as a coolant for the working parts. In many cases, the fluid acts as a sealing medium. In some tractors the same fluid used in the hydraulic system must also lubricate gears, bearings, etc., in the tractor transmission. It should be capable of holding its viscosity through a wide temperature range. It should resist oxidation, protect machine parts against rust and corrosion, and be capable of separating air and water from itself quickly.

Effects of Using Wrong Oil in System

Improper viscosity of the oil may create a back pressure on the system, due to the resistance of the oil to flow. Decomposition of metal parts and seals may be caused by oxidation. (Oxidation occurs when the fluids combine with oxygen to form organic acids. These acids are harmful to the metals and seals.) Foaming of the oil will cause many problems in a hydraulic system. Since oil is not compressible and air is, the operation of cylinders and motors will be spongy or irregular if air is present in the system. The effects of improper lubrication and improper rust protection are obvious. Oil that is too heavy may cause cavitation (starving of the pump) in cold weather as the heavy oil will not flow through the inlet line freely.

Selection and Use of Hydraulic Fluids

The manufacturer of any machine undertakes considerable research in the selection of the oil most suitable for the machinery he produces. The service manual supplied with each machine will specify the correct oil to use. It is very unwise to differ from the manufacturer's recommendation as the oil you select may lack something that could create some of the problems previously mentioned.

Having selected the correct oil, the next important step is using it correctly. The worst enemy of a hydraulic system is dirt and contamination. Dirt is often allowed into a hydraulic system through the oil filler opening when the machine is being serviced.

When checking the oil in a system, wipe off all dirt from around the filler cap and neck before removing the cap. Use the same precaution when opening the cap on the oil barrel or can. Fill

through a strainer type of funnel, and replace the lids on both the reservoir and oil can immediately.

Care and Maintenance

The hydraulic system will give long and trouble-free service if it is kept supplied with adequate clean oil at all times. Check oil levels frequently to prevent the system from running low on oil, and if the oil appears to be thick or dirty, change both the oil and the oil filters. Always refer to the owner's manual for recommended regular service to filters and oil.

TRACING HYDRAULIC TROUBLES

Hydraulic systems on tractors and farm machinery are well engineered, efficient and comparatively trouble free, but like all machinery there are occasional problems to be corrected. Since all hydraulic systems consist of a number of components such as pumps, valves, cylinders, motors, etc., connected together by either pipes, hoses or manifolds, these problems can be very difficult to trace. Unlike many mechanical problems the defects and their causes cannot be seen while the system is in operation.

While the pump may be considered to be the heart of the hydraulic system it is not usually the cause of problems. The most common error in repairing systems is to jump to conclusions as to where the fault lies without tracing the problem properly. This practice often leads to replacing or overhauling the pump when it is not really defective. An understanding of the following fundamentals will be helpful in tracing problems: There are two basic characteristics of a hydraulic system that affect its performance, rate of flow and pressure. Flow is the movement of oil created by the pump; pressure is created in the oil when the flow is resisted by the load or work being done. If the problem involves a lack of power or lifting capacity, then the trouble relates to pressure. If the problem involves a lack of speed of operation or slow lifting, the trouble relates to flow.

Follow these steps in troubleshooting a complete hydraulic system.

1. Determine if the trouble is a lack of flow or a lack of pressure. This can be done by operating the system first without a load and then with a load. If the system operates normally without a load but fails under load then the problem is related to pressure. If the system operates slowly with or without a load then the problem relates to rate of flow.
2. If the problem is a lack of flow check for these defects in this order: (a) Oil in reservoir—there must be sufficient oil in the reservoir to assure that the pump will receive oil at all times without taking in air. (b) Oil is too thick or too dirty—heavy or dirty oil will not flow freely into the pump and therefore will reduce the pump output or flow. Always use good-quality hydraulic oil as recommended by the machine manufacturer. (c) Restricted pump supply line—the pump cannot pump any more oil than will flow into it easily. A blocked or dirty inlet filter will therefore reduce the flow from the pump. (d) Leaking inlet line—a cracked or loose pump-supply line will allow air into the pump along with, or instead of the oil; this will reduce the flow and cause foaming of the oil. When foaming exists in a system the hydraulics will operate spongy, jerky and noisy. (e) Leaking pressure lines or leaking valves or cylinders—the pump may be producing the correct flow but losing some of it through leaking pressure lines. Leaks on internal lines are difficult to trace without the use of a flowmeter but may sometimes be seen through inspection covers on tractors. (f) If all the above items are in order and the flow is low then the trouble will be at the pump. Remove the pump for repair or replacement.
3. If the problem is a lack of pressure check for these defects in this order: (a) The pressure-relief valve may be stuck partly open (usually caused by dirt in the system) or opening at too low a pressure. To set the pressure-relief valve it is necessary to use a pressure gauge and know the correct maximum system pressure. With a gauge "teed" into the pressure line (pump-output line) operate a control valve to move a cylinder all the way to its limit and read the pressure gauge. If the relief valve is opening at a pressure lower than required then clean and adjust or replace the relief valve consulting the manufacturer's setting procedures. (b) If the pressure gauge is reading less than maximum pressure but the relief valve is not opening, then *either* the flow is escaping somewhere else or the pump is failing under pressure. To determine which of these is the problem it may be necessary to disconnect and plug the line leading out of the control valve or if

possible the line immediately after the relief valve. If pressure is now normal then the problem is in the part of the system that has been disconnected. If pressure is still low then the problem is at the pump.

4. Leaks may develop at the piston seals in hydraulic cylinders which may cause the cylinder to lift slowly under load, may allow the cylinder to slip under load or may cause an abnormal build up of pressure in the system when it is carrying a load. A leaking single-acting cylinder is easy to detect as the oil leaking past the piston will be visible as it escapes from the cylinder. A leaking piston on a double-acting cylinder will not be visible as both ends of the cylinder are connected to the hydraulic system. The easiest way to test a double-acting cylinder is right on the machine that it is part of. Extend the cylinder all the way out and then shut off the system and disconnect the hose or pipe from the end of the cylinder toward the rod. Start the system operating and with the valve in the position to extend the cylinder allow the oil to run at full pressure over the relief valve. If the cylinder piston is leaking, oil will run out of the open fitting during the test. If there is no sign of leakage, repeat the test with the cylinder fully retracted and disconnect the other line. This second test is necessary as pistons will sometimes leak in one direction only.

5. To check a control valve for internal leakage proceed as follows: If the control valve unit has no relief valve contained within the same housing it may be easily checked for internal leaks by holding the valve in an open position so that oil extends the cylinder all the way to the end, then remove the line that returns from the valve to the reservoir and observe for any flow of oil. If there is any flow of oil at this line, while the cylinder is still under pressure, then there is leakage in the valve. This check cannot be done if the relief valve is located in the main valve body as the return line is also used by the relief valve. To check this type of valve it is necessary to connect a flowmeter or hydro-analyzer to the system and check the valve for leakage at a pressure lower than the relief-valve setting.

The diagram (Figure 32) illustrates the order to follow in troubleshooting a hydraulic system without use of a flowmeter. If a flowmeter is used the pump should be checked at the same time as the inlet lines and filters.

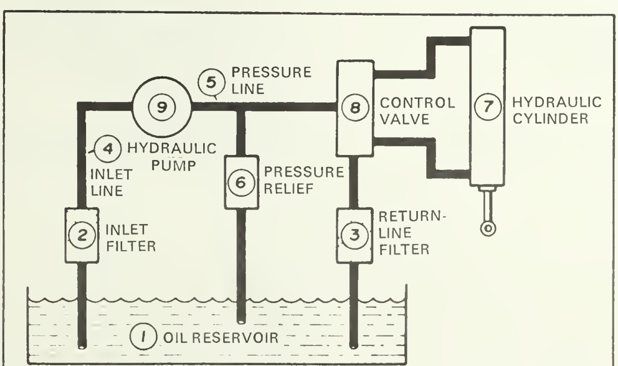

Figure 32 Diagram illustrating the order to follow when trouble-shooting a hydraulic system without the use of a flowmeter.

CONVERSION FACTORS — METRIC AND ENGLISH SYSTEMS

LINEAR

1 in. (inch) = 25.4 mm (millimetres)
1 mm = 0.03927 in.
1 ft (foot) = 304.8 mm
1 mm = 0.0032 ft
1 yd (yard) = 0.9144 m (metres)
1 m = 1.0936 yd
1 mi (mile) = 1.6093 km (kilometres)
1 km = 0.6213 mi

AREA

1 in.^{2} = 645 mm^2
1 mm^2 = 0.00155 in.^{2}
1 ft^2 = 0.0929 m^2
1 m^2 = 10.76 ft^2

VOLUME

1 in.^{3} = 16380 mm^3
1 mm^3 = 0.00006 in.^{3}
1 mL = 1000 mm^3
1 mL = 0.061 in.^{3}
1 in.^{3} = 16.38 mL
1 imp. gallon = 4.54 L (litres)
1 L = 0.22 imp. gal
1 U.S. gallon = 3.7853 L
1 L = 0.264 U.S. gal
1 imp. fluid ounce = 28.4 mL
1 U.S. fluid ounce = 29.6 mL

VELOCITY

1 ft/s (foot/second) = 3.048 mm/s
1 mm/s = 0.0032 ft/s
1 in./s = 25.4 mm/s
1 mm/s = 0.039 in./s

POWER

1 hp (horsepower) = 746 W (watts)
1 hp = 0.746 kW
1 kW = 1.34 hp

MASS

1 oz (ounce) = 28 g (grams)
1 g (gram) = 0.035 oz
1 lb (pound) = 0.453 kg (kilograms)
1 kg = 2.205 lb
1 t (tonne) = 1000 kg
1 ton (2000 lb) = 0.907 t
1 tonne (t) = 1.1 ton

FORCE

1 lb-f (pound-force) = 4.448 N (newtons)
1 N = 0.2248 lb-f
1 kg-f (kilogram-force) = 9.806 N
1 N = 0.1019 kg-f
1 dyne = 0.00001 N

TORQUE

1 ft-lb = 1.355 N•m (newton-metres)
1 N•m = 0.738 ft-lb
1 in.-lb = 0.1129 N•m
1 N•m = 8.85 in.-lb

PRESSURE

1 lb/in.^{2} = 6.89 kPa (kilopascals)
1 kPa = 0.145 lb/in.^{2}
1 bar = 100 kPa
1 atmosphere = 101.325 kPa

FLOW

1 imp. gal/min = 4.54 L/min
1 L/min = 0.22 imp. gal/min
1 U.S. gal/min = 3.785 L/min
1 L/min = 0.264 U.S. gal/min
1 in.^{3}/min = 0.273 mL/s

TEMPERATURE

degrees Fahrenheit = (°C ÷ 0.56) + 32
degrees Celsius = (°F − 32) × 0.56